



A New Paradigm of Colliders - Zero Emittance Limit

$x_n \sim 5 \times 10^{-8} \text{ m} - \text{rad}$ for laser-accel channel

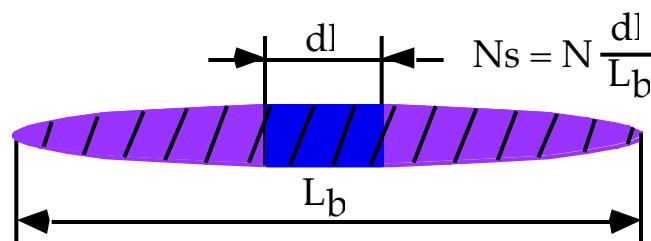
$N \sim 10^8 / \text{bunch}$

Spot-size $< \text{\AA}$

- Are there injectors capable of producing them ?
 - Photocathode : $\hat{\lambda} \sim$
 $\sim 50 \text{\AA}$ to 5000\AA radiation on a
cathode depending on aspect ratio.
 - Emittance selection
- What about physics at the collision point ? Luminosity as a simple classical overlap of geometric areas ? Is classical beamstrahlung still relevant ? What if the electromagnetic effect are 'channeled' instead of being in free space ?

Advantages

1. Strength of incoherent signal on other beam particles (noise) depends on the number of particles in a sample, N_s



which is defined by the bandwidth of the overall system. (Compare 4×10^{13} Hz optical frequency bandwidth with 4×10^9 Hz microwave frequency bandwidth). Correspondingly, OSC has a potential to 10^4 faster damping than microwave stochastic cooling.

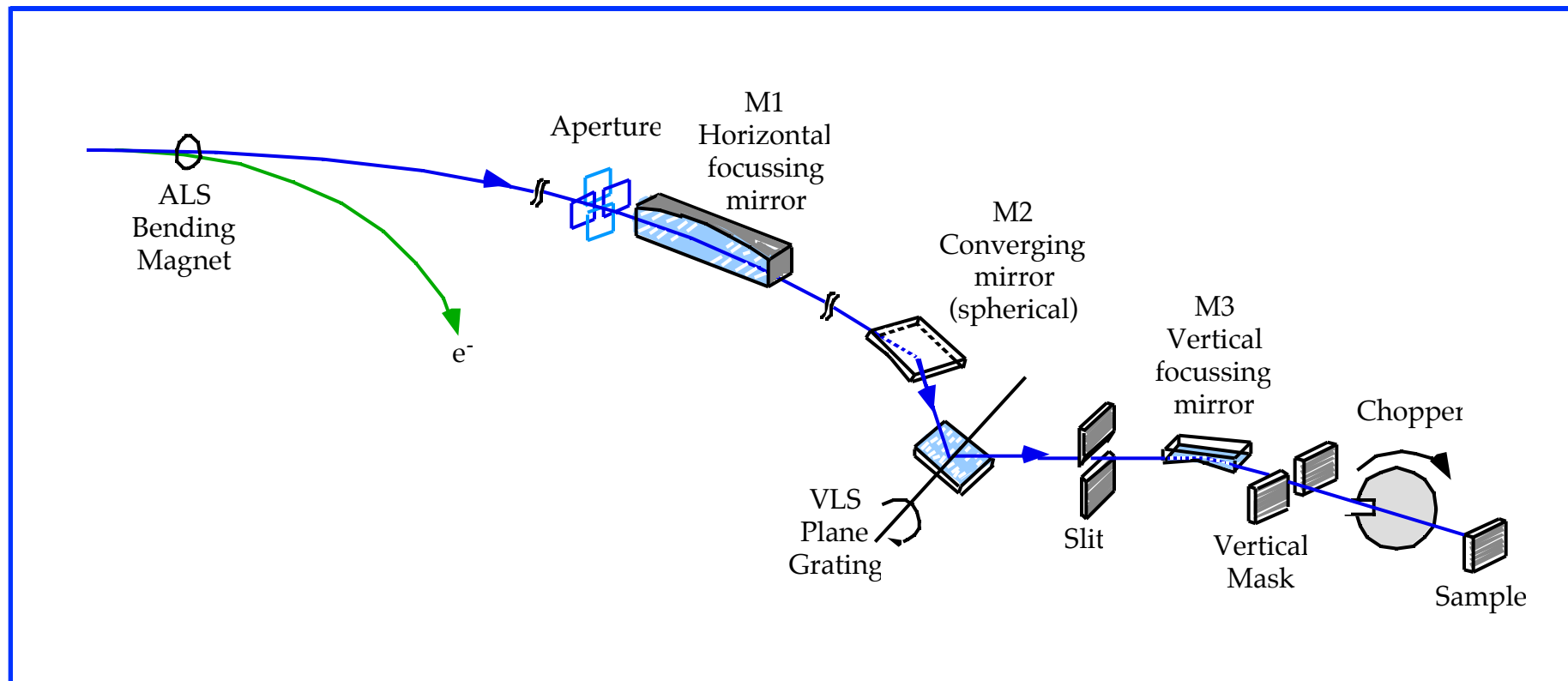
2. Alternatively, for the same damping time as in microwave stochastic cooling (very slow of OSC) we find a difference in the required amplifier power:

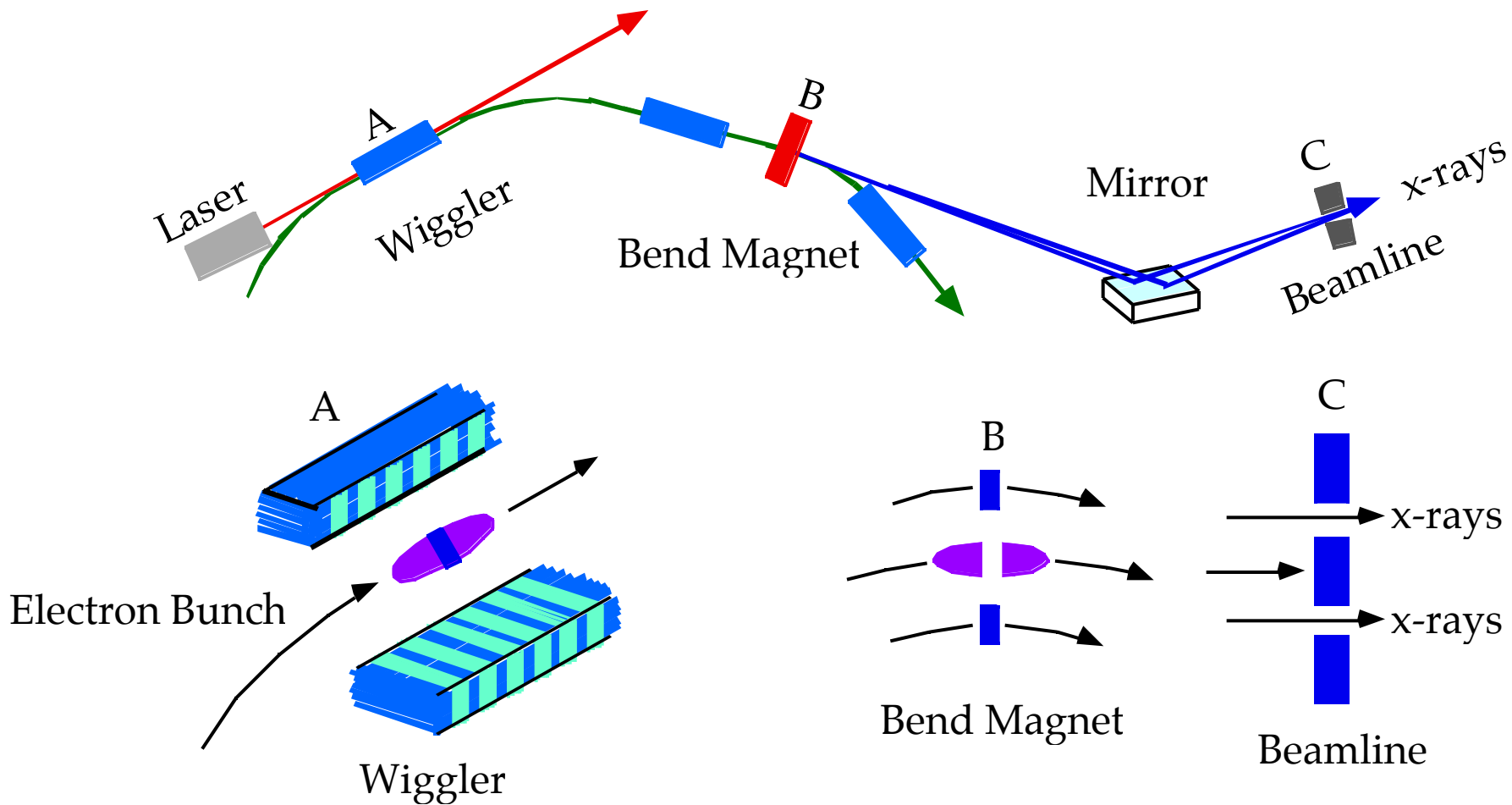
0.1 W for OSC

10^3 W for microwave cooling



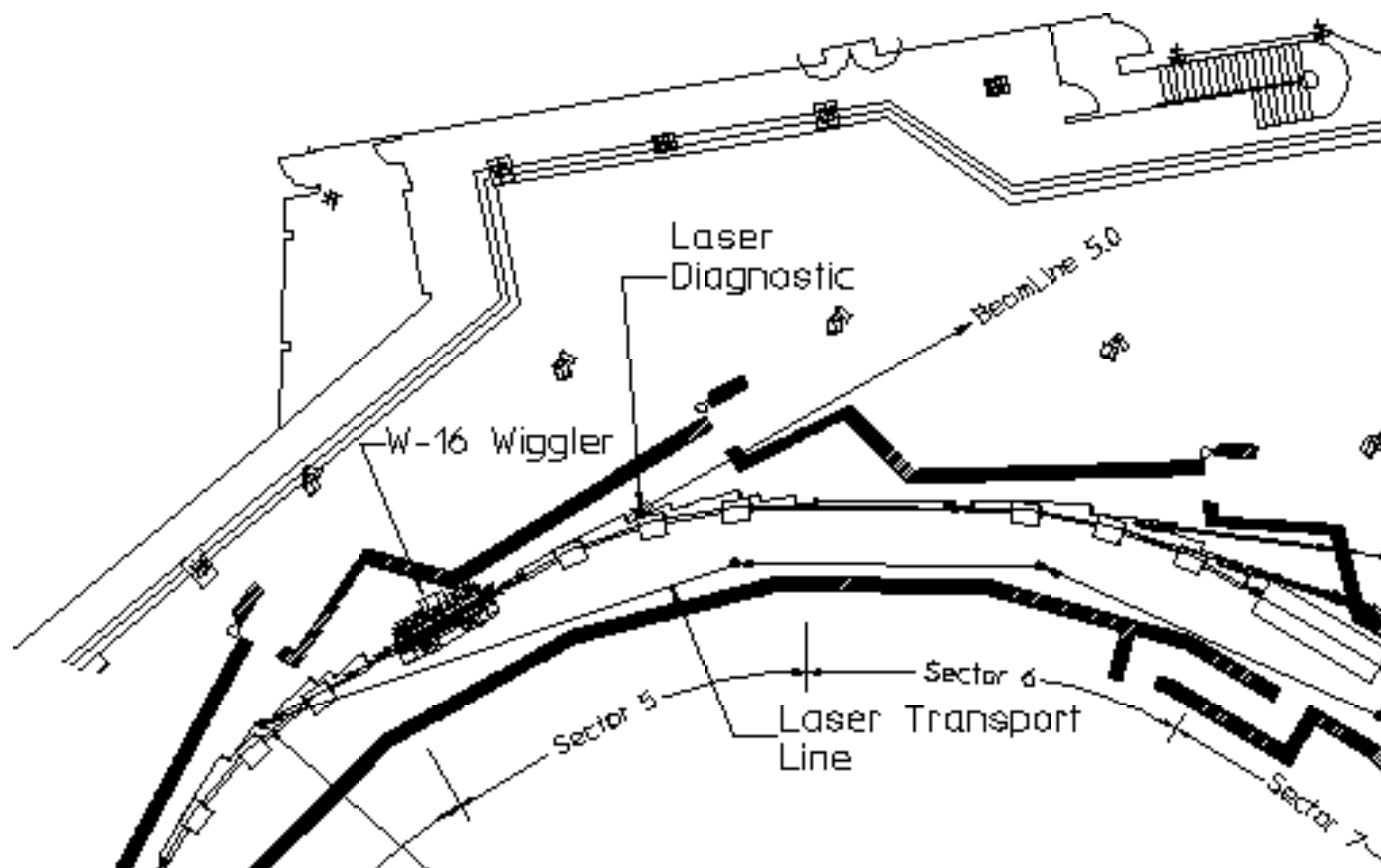
Bending Magnet





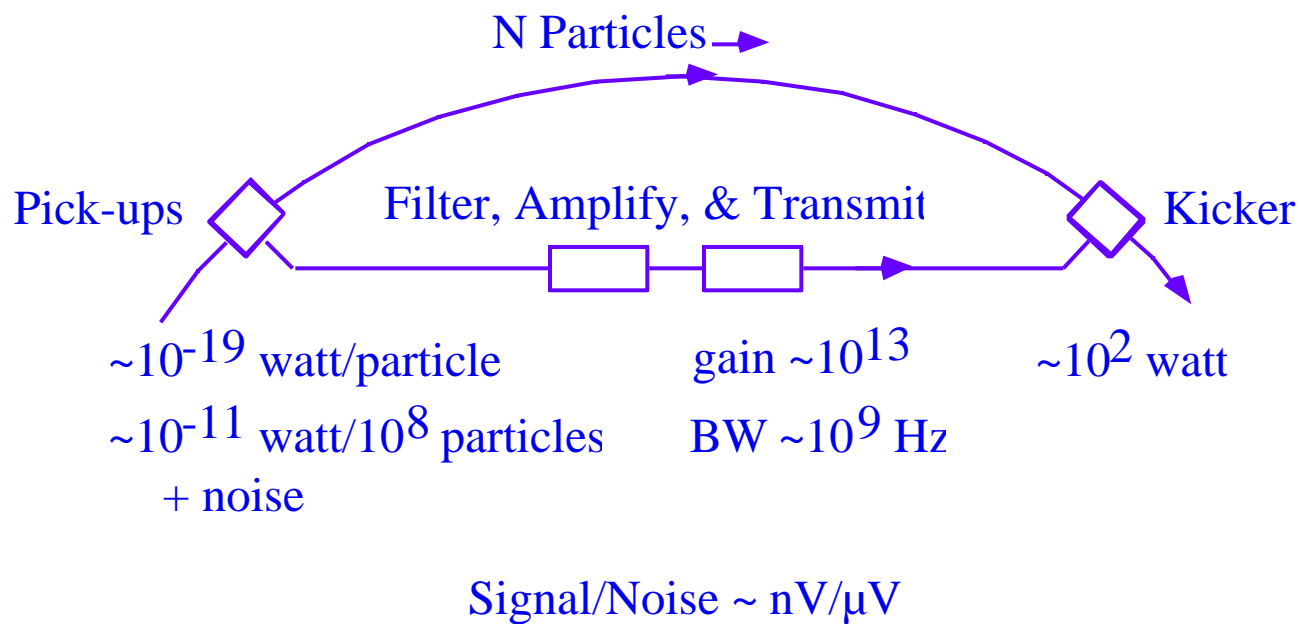


ALS Layout Implementation



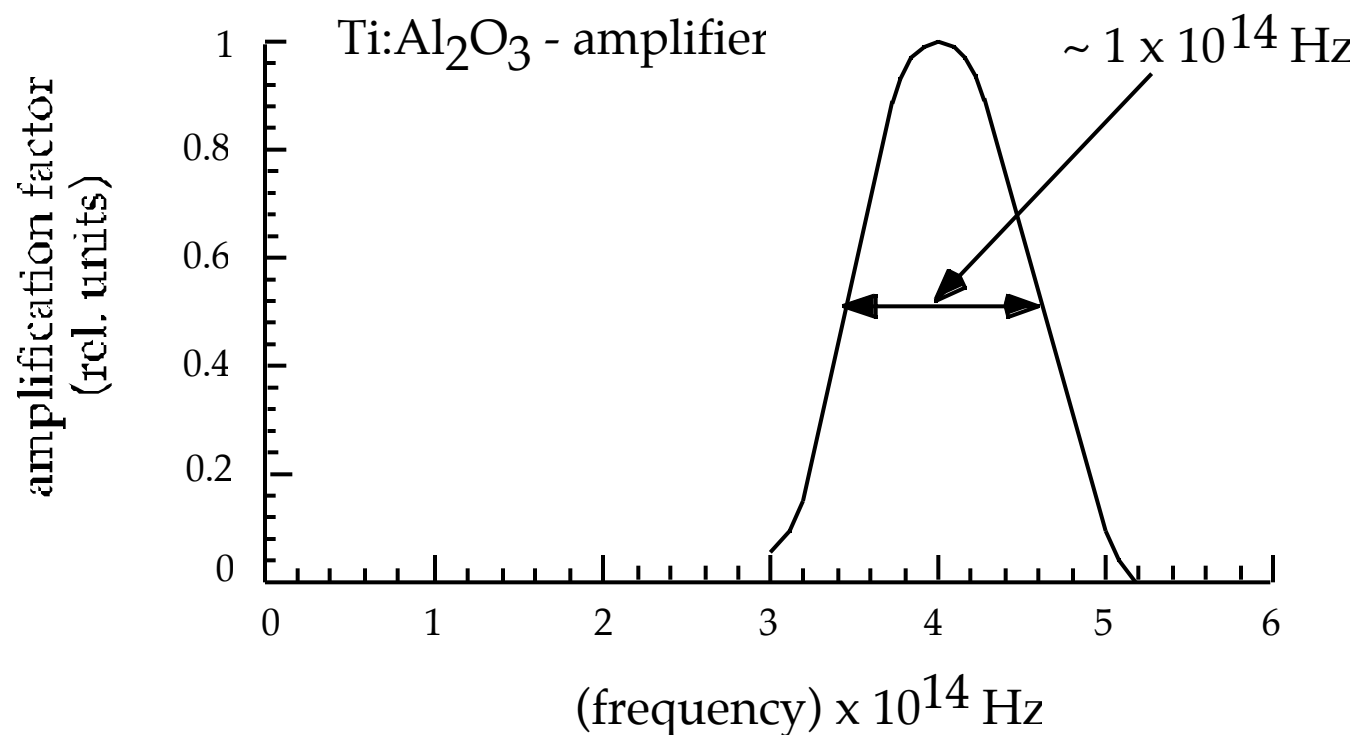


The Beam Cooling Scheme





Broadband Optical Amplifiers (Ti:Al₂O₃, DYE)





Consolidated R&D Program

- Infrastructure needed for meaningful and serious experimental R&D is already in place (see plans for 71 L'OASIS laboratory and electron beam vault downstairs).
- State-of-the-art femtosecond Table Top Terawatt laser already procured. THE HIGH POWER AMPLIFIER SECTION IS OBTAINED THROUGH COLLABORATIVE AGREEMENT WITH Prof. Roger Falcone OF THE PHYSICS DEPARTMENT AT BERKELEY.
- Many collaborators from UCB campus provide significant leverage for the program:
 - James Siegrist : Acceleration diagnostics
 - Marjorie Shapiro : Acceleration diagnostics
 - Roger Falcone : Laser channeling and THz source development
 - Jonathan Wurtele : Theoretical beam dynamics support
 - Others : J. Bokor (UCB), P. Buxbaum (UM, Ann Arbor)(THz source).
- Many LBNL investigations :
 - Wim Leemans
 - Swapam Chattopadhyay
 - William Fawley
 - Alexander Zholents
 - Max Zolotorov
- Strong local expertise in lasers
 - R. Schoenlein, LBNL
 - C.V. Shank, LBNL
 - J. Heritage, UCD
 - LLNL team

Consolidated R&D Program...con't



(con't)

Consolidated R&D Program

- Collaborative investigation from SLAC :
R. Siemann (100 GHz source)
D. Whittum (100 GHz source)
- Many students involved (3 from UC Berkeley, 1 MIT, 1 U. Paris @ Orsay)
- Meaningful laser guiding and channeling experiment already planned.
Two Ph.D. dissertations are involved.
- Need to secure a high quality (in terms of brightness) low energy (about 20 MeV) electron beam source in the future.

MOC with UC Davis for 11.4 GHz AXF photocathode gun development.

- Support needed : 2 FTEs/year Operating and \$230k Equipment/year for five years to demonstrate the technological feasibility of a 1 GeV module.



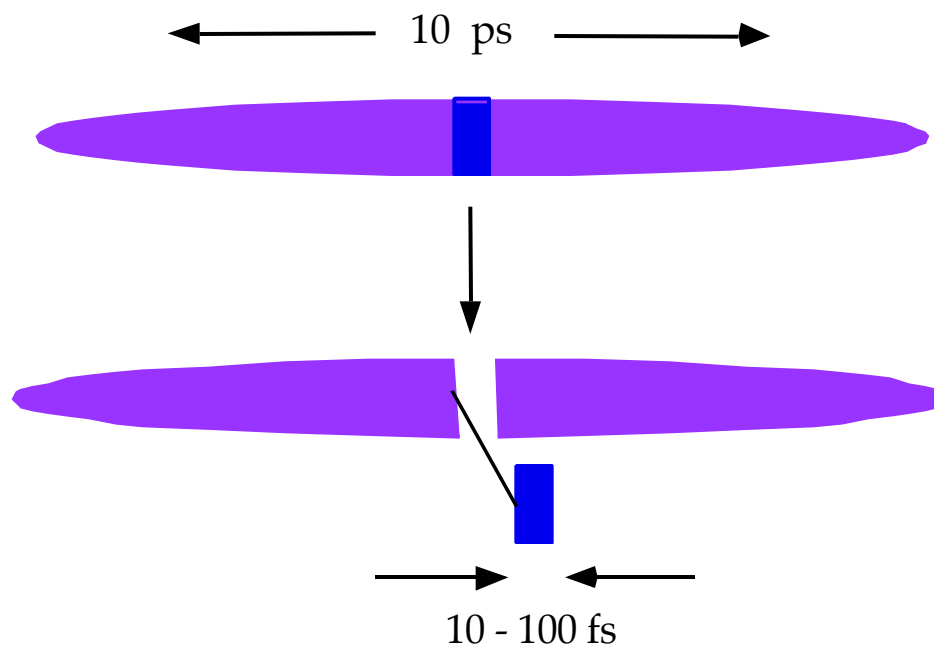
Critical Elements for the Success of Laser Acceleration :

- Physics of the acceleration channel supporting a phase-space density and repetition rate compatible with the application, e.g. high energy colliders or radiation sources, etc.
- Just as today's microwaves from klystrons are suitably guided by linac waveguide structures without diffraction for efficient coupling to the beam, we will have to learn how to focus strongly (in order to achieve high fields) and guide simultaneously short laser pulses over macroscopic distances of cms. without diffraction in order to use them for particle acceleration.
- We would have to master the relative amplitude, phase and frequency control of lasers similar to today's rf technology, but scaled to laser frequencies.



Femtosecond Laser - Electron Beam Interaction

Femtosecond 'Tickle' and Slicing of Picosecond Electron Beams





“ Here I would like to make an analogy. There are three kinds of physicists, as we know, namely the machine builders, the experimental physicists, and the theoretical physicists. If we compare those three classes, we find that the machine builders are the most important ones, because if they were not there, we would not get into this small-scale region. If we compare this with the discovery of America, then, I would say, the machine builders correspond to captains and ship builders who really developed the techniques at that time. The experimentalists were those fellows on the ships that sailed to the other side of the world and jumped upon the new islands and just wrote down what they saw. The theoretical physicists are those fellows who stayed back in Madrid and told Columbus that he was going to land in India.”

Victor F. Weisskopf in
The development of the concept of an elementary particle.



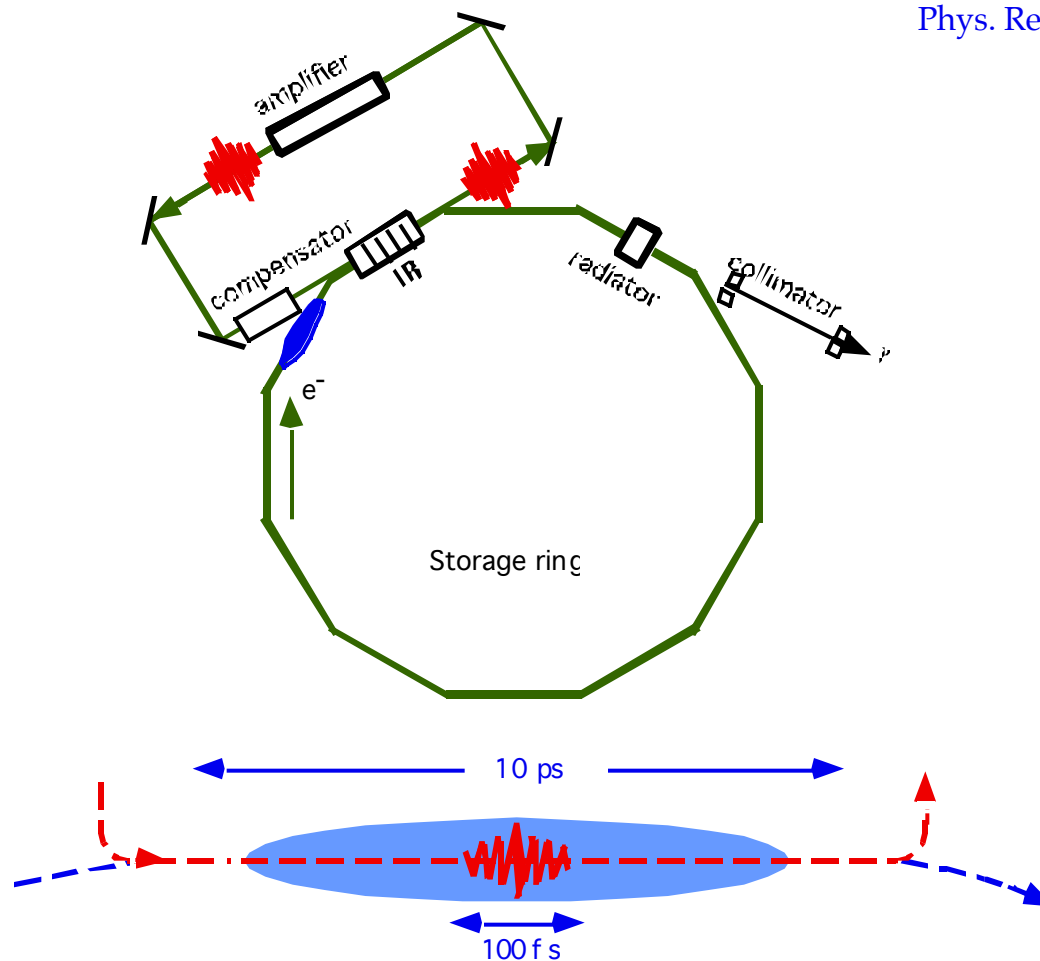
High Frequency Diagnostics and Optical Stochastic Cooling for Future Colliders

- Beam manipulation on a femtosecond time scale (i.e. THz frequency scale)
- Stochastic phase-space cooling at optical frequencies
- Applications and relevance to :
 - TeV 33 (to achieve the high luminosity)
 - Muon colling
 - Laser acceleration, linear colliders, etc.



Femtosecond Slicing in a Storage Ring Implementation in the ALS

A.A. Zholents & M. Zolotarev,
Phys. Rev. Lett. 76, 916-918 (1996)



Laser Manipulation of Beams : A New Thrust

**Presented by
Swapan Chattopadhyay**

DOE/HEP Review

LBNL

April 11, 1996



- Lasers : well-known to have high electric and magnetic fields
- Lasers can be coupled to particle beam for net longitudinal acceleration
 - in free space in presence of boundaries and apertures
 - in free space without boundaries via nonlinear higher order mechanisms and in presence of magnetic fields
 - via direct coupling of lasers to a plasma-like medium



Laser Acceleration

The microwave technology at frequencies between a few MHz and a few GHz has been the work horse for particle accelerators since World War I and II. Powerful radio frequency power sources — such as cw tetrodes and pulsed klystrons, with a great deal of flexibility in amplitude, phase and frequency control — have been the drivers of particle storage and acceleration in circular and linear accelerators. Along with such versatile power sources, came the necessity to control and manipulate particle beams via radio-frequency electromagnetic fields to a high degree of precision. The RF and beam feedback systems, bunch rotators and Landau cavities, etc. all have been employed successfully to benefit collider operation. As the science and technology of RF progressed, the demands on the spectral purity of RF components for accelerator applications rose precipitously.



Mini-Workshop on Laser Acceleration October 6, 1995

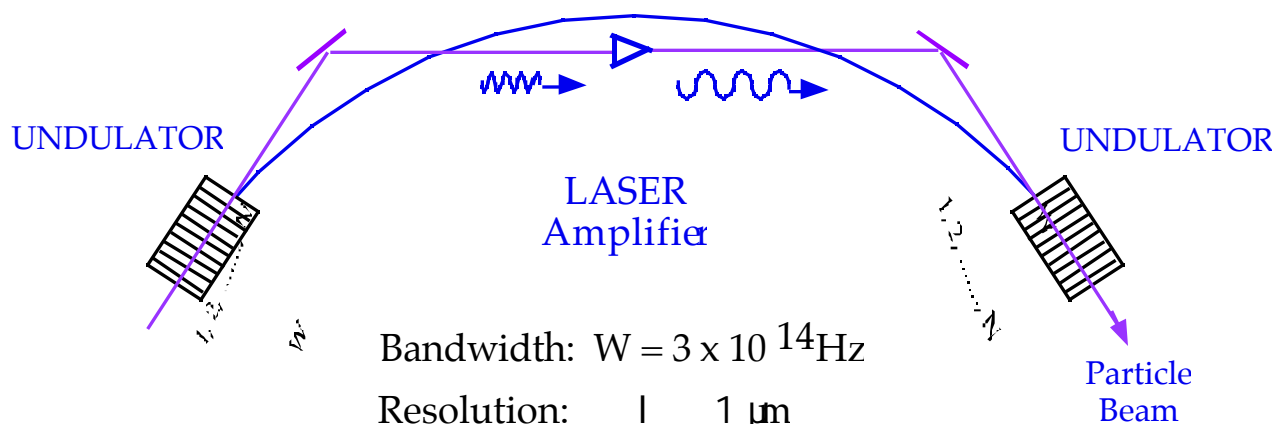
Summary Issues

- Channeling radiation experiment - - precise specification of what could be observed with existing SLC beam at 50 GeV and existing macroscopic crystal. Design the experiment to validate channeling physics.
- Requirements on a THz radiation source for powering a 100 μm linac structure.
- Accurate calculation of energy loss (loss factor) in crossed laser scheme of Huang and Byer including frequencies up to the bunch cut-off frequency.
- Specification of injection beam characteristics, both longitudinal and transverse, for crossed laser and laser-plasma schemes that can be scaled to collider requirements.
- Specify low emittance gun or source development with specific parameters for beam phase space.

Optical Stochastic Cooling

The Idea

A. Mikhailichenko & M. Zolotarev,
Phys. Rev. Lett. 71, (25), 4146 (1993).



Bandwidth: $W = 3 \times 10^{14} \text{ Hz}$

Resolution: $1 \text{ } \mu\text{m}$

Gain: $g \text{ } 10^4$

#Photons/charged particle $\sim N_W K^2$

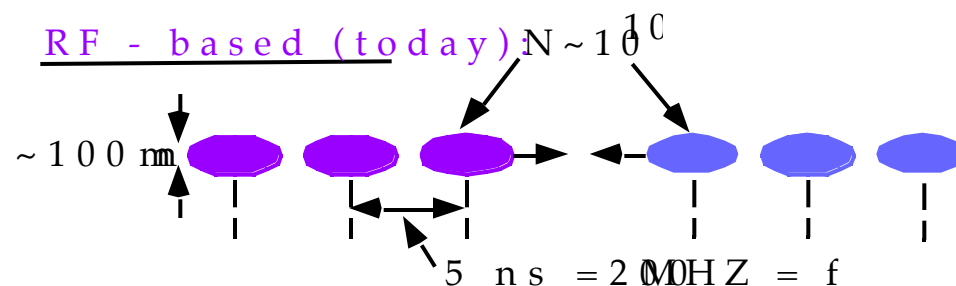
Weak undulator : $K \sim 0.1 \quad n/n_e \sim 1/137$

Strong undulator : $K \sim 1 \quad n/n_e \sim 1$

- Quantum Noise
- Signal/Noise
- Coherent Radiation



Operations of Increasing Order in Smaller Dimensions and Higher Frequencies



Drivers

RF ~ GHz

Super RF ~ 100 GHz

THz

Laser

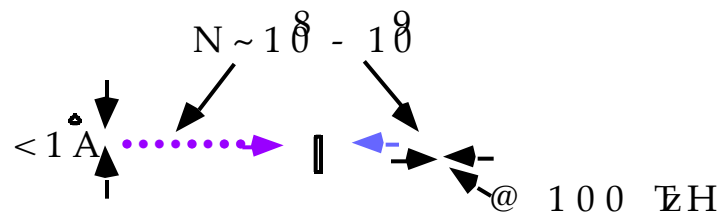
Structure

cms

100 μ m

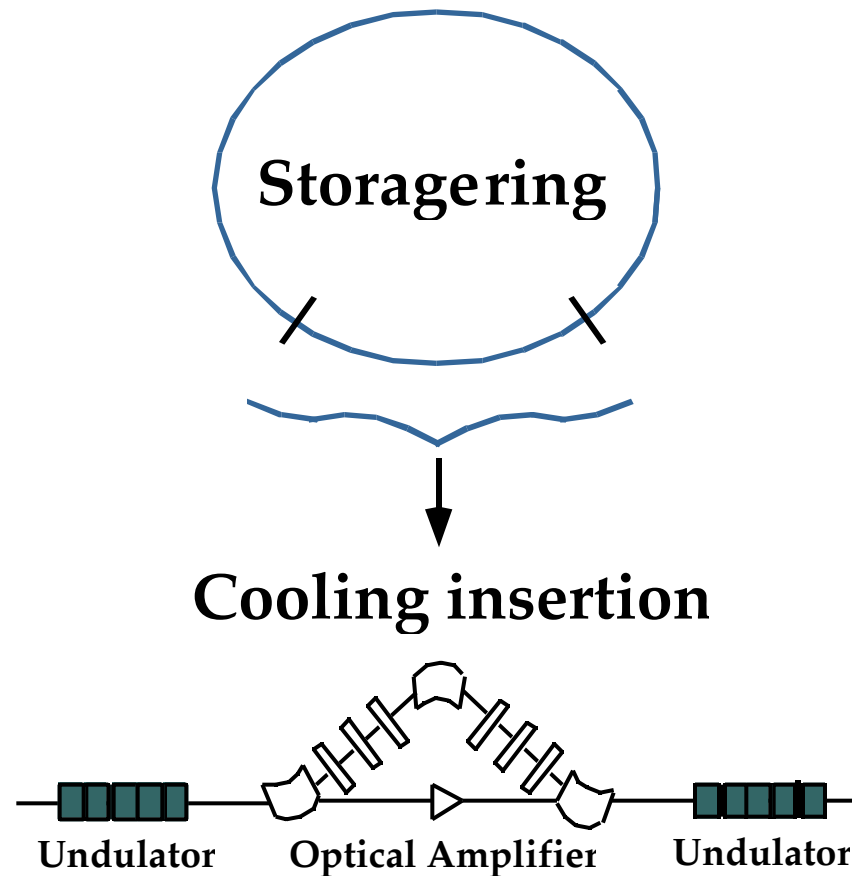
μ ms in place

Laser-beams





Optical Stochastic Cooling



Bypass forces each particle to meet its own amplified radiation in the second undulator where it receives a "coherent" energy kick due to interaction with this radiation.

A. Zholents & M. Zolotarev,
Phys. Rev. E50 (4), 3087 91994)

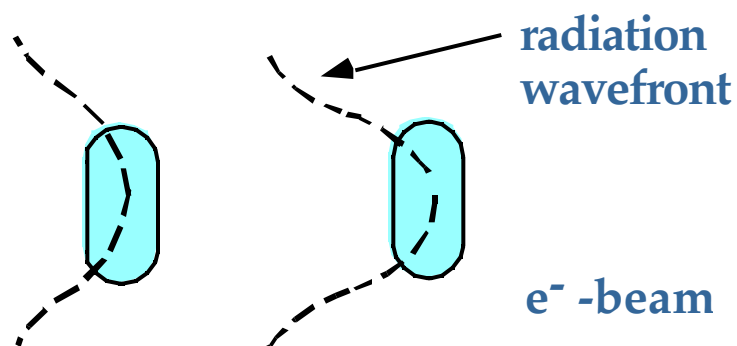


Primary Focus of the Experiment is to Understand :

- Photon statistics and phase space $d\mathbf{o}\cdot\mathbf{f}$
- Overlap —"transverse"—of the electron beam and undulator radiation wavefront
- Coherence volume in the transverse plane :

$$x \quad x \quad \sim \quad \lambda$$

- Distortion of radiation wavefront due to amplification, propagation, etc.





Program Description

- Study physics of, and develop techniques for, interaction of electron beams with lasers and plasmas, towards the development of ultra-high gradient acceleration and high energy collider diagnostics.
- Evolution of the overall CBP experimental program in constant dialogue with other CBP groups —

Beam Electrodynamics (J. Corlett)

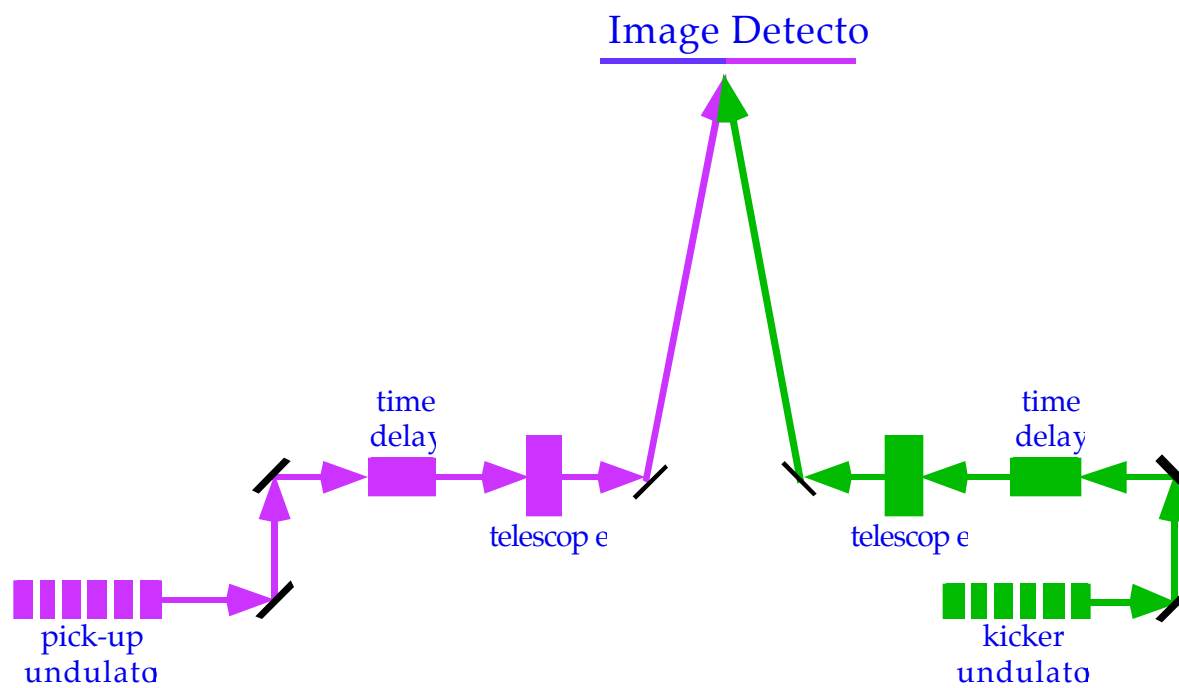
Theory (K.-J. Kim)

Collider Physics (A. Sessler)

and other special project needs of CBP as a National program
in High Energy Physics (S. Chattopadhyay)



Test of "Non-Mixing" via Fringe Visibility



Preservation of fluctuations in the electron beam in the passage between undulators. Visibility of the interference pattern :

$$\text{Visibility} = \exp - \frac{(k - \ell)^2 + (k\ell)^2}{2}$$



*Today we are contemplating going beyond the GHz microwave rf technology to mm-wave and even THz radiation sources and eventually, maybe by state-of-the-art short pulse high power compact lasers as work horses for particle accelerators. There exist possibilities of generating ultrahigh electromagnetic fields by coupling these sources and today's lasers either to a channel in free space with suitable boundaries. or to a suitable macroscopic medium like a plasma. However, just as in today's microwave technology involving beam manipulation over fractions of **mm**s in time-scales of **picoseconds** at frequencies of **GHz**, one would have to learn to manipulate and control signals and particles at optical wavelengths of **microns** , in time-scales of **femtoseconds** at frequencies of **THz** and higher in order to take advantage of today's lasers. For example, the development of femtosecond kickers, choppers, bunch rotators etc., and THz manipulation of beams will be one of the most challenging jobs for beam scientists, but needs to be accomplished for further progress.*



Topics Topics Topics

- Laser Acceleration
- High-Frequency Diagnostics & Optical Stochastic Cooling
- Femtosecond Laser-Electron Beam Interaction
- Consolidated R&D Program



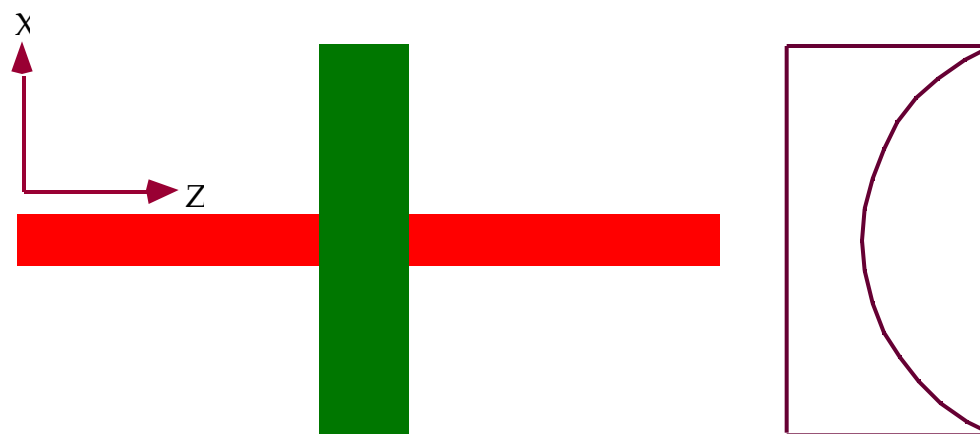
Workshop Goals :

- A. Come up with parameters for 1 GV/m accelerators module, scale
 - 1) TeV collider
 - 2) GeV - beam driven radiation source
- B. Specify "injector" characteristics
- C. Specify laser focusing and guiding requirements
- D. Specify laser amplitude, phase, pulse-format control
- E. Specify plasma control
- F. Any new physics ?



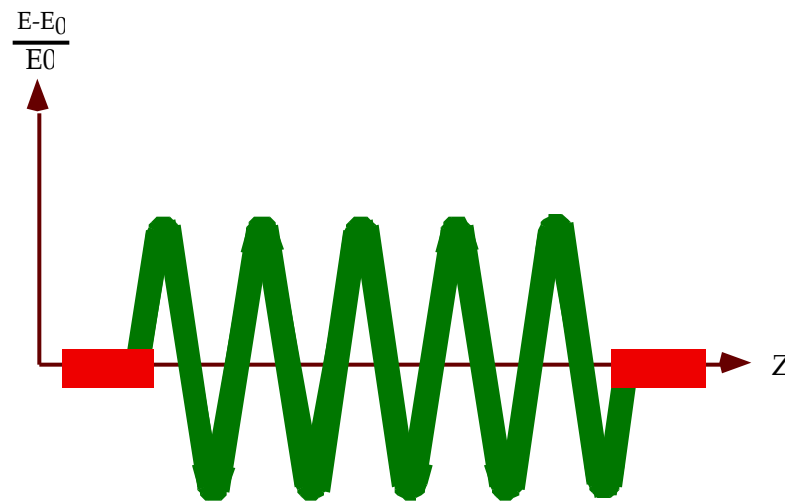
- Demonstration experiment planned using the LBNL Advanced Light Source Booster Synchrotron. Preliminary beam measurements indicate that AN EXPERIMENT TO DEMONSTRATE THE FEASIBILITY OF THE THz SIGNAL EXTRACTION FROM AN ELECTRON BEAM IS ENTIRELY POSSIBLE WITH THE ALS BOOSTER BEAM.
- A magnetic lattice with suitable properties have been designed.
- A considerable amount of leverage is provided by the interest of the ALS accelerator staff in demonstrating the experiment.
(see the design layouts and data).

- Electrons (previously energy modulated) will be spatially separated in a dispersive region



- Top view on a fraction of the electron bunch and particle density distribution in the horizontal plane

- Few mJ's in the laser pulse is enough to produce modulation amplitude of 5-10 σ_e .



- Longitudinal phase space portrait of a fraction of the electron bunch after interaction with the laser pulse